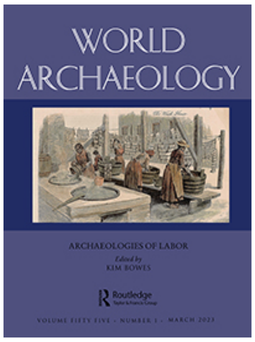

World Archaeology

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/rwar20

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To cite this article: M Berihuete-Azorin, C Kerfant, E Allué, A Burguet-Coca, F Burjachs, I Expósito Barea, T Fernández Iriarte, B Garay Palacios, J Revelles, A Robledo, D Rodríguez Antón & C Speciale (13 Aug 2024): Archaeobotany in an era of change and challenge: potential and fragility of macro- and micro-remains, World Archaeology, DOI: 10.1080/00438243.2024.2382140

To link to this article: https://doi.org/10.1080/00438243.2024.2382140

WORLD ARCHAEOLOGY
https://doi.org/10.1080/00438243.2024.2382140

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Archaeobotany in an era of change and challenge: potential and fragility of macro- and micro-remains

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ABSTRACT
Apart from helping us understand past communities' response to climate change and their plant management resilience mechanisms, archaeobotanical information may also serve as a basis to rethink our economic system and implement new solutions to current challenges (e.g. re-adopt forgotten crops or implement circular economy models). Already fragile by nature, the integrity of archaeobotanical heritage is affected by current climate events, such as changes in temperature and precipitation. One consequence is the loss of precious knowledge about past economies and human-environment interactions and its potential to inform us on questions relevant to the present and future. With the Iberian Peninsula as an example, we present a thoughtful insight into the manifold kind of information derived from archaeobotanical assemblages and the harm in losing it. Finally, we call for action to fight against climate change while drawing archaeologists' attention to the importance of protecting archaeobotanical heritage.

KEYWORDS
Past cultivars; resilience; circular economy; ethnobotany

Introduction

The factors affecting the destruction of archaeological heritage and material are many, from insufficient regulations and limited use of systematic excavation and sampling methodologies, to looting of archaeological sites. The current climate crisis, which implies global warming and extreme climate phenomena like floods, drought or wildfires, not only menaces the lifeways of most living beings on Earth but also adds a new factor to the list. The consequence is a serious risk to the traditional ways of life, considered the main way to preserve ecological diversity (e.g. Yin 2023) and offer resilient alternatives to capitalism and westernized societies (e.g. Berkes, Folke, and Gadgil 1994), which are thus endangered. Those ways of life are accessible mainly through traditional

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Supplemental data for this article can be accessed online at https://doi.org/10.1080/00438243.2024.2382140.

ecological knowledge (TEK) and archaeology and will remain obscure if we do not make haste to study, record and preserve as much information as possible. The TEK corpus of information has been growing since the 1990s. Cultural globalization phenomena drew researchers' attention to communities still holding any kind of traditional knowledge about ancestral uses of resources (mainly plants and animals). One result, among others, has been the Nagoya Protocol (Secretariat of the Convention on Biological Diversity, 2011) to ensure the equitable sharing of benefits stemming from the use of genetic resources, and thus contributing to the conservation of biodiversity.

Biological and cultural heritage are intimately connected and thus the erosion of one of them inevitably entails the loss of many aspects of the other (Emperaire 2000; Russell and Kueffer 2019). However, archaeology has not yet developed an equivalent framework to enable the systematic recovery of biological remains and safeguard the perishable archaeological record from the menace of climate change. Studies drawing attention to the urgency of a specific protocol are quite recent (Burke et al. 2021; d'Alpoim Guedes et al. 2016; Hudson et al. 2012). Furthermore, only a few of them focus on areas where the effects of climate change are most pronounced, such as coastal or river zones where sea-level rise is more imminent, or areas affected by glacial melting (Fenger-Nielsen et al. 2020; Howard et al. 2008; Sitzia, Peters, and Lisci 2022).

Within archaeology, archaeobotany is particularly sensitive to information loss. This field is devoted to the study of plant remains, including micro-remains (pollen, non-pollen palynomorphs or NPPs, phytoliths, starch grains) and macro-remains (mainly wood, underground storage organs, seeds, and fruits) (for clarification of these concepts see the Glossary in the Supplementary material). Their functional differences within plants result in different types of archaeological information. Phytoliths, for instance, are mainly representative of the vegetative parts of the plant (with the exception of the fruit core), and thus are local indicators of their *in situ* presence, while pollen grains are only found in the flowers, and are evidence of their presence through their propagation (Piperno 2006). All in all, these remains have in common their fragility while displaying different degrees of preservation, and are evidence of past vegetation, environment, food, fuel, medicine, or raw material (Pearsall 2015). As a result, these materials are an invaluable source of information about many aspects of past societies' organization, economy and all kinds of maintenance activities that would remain unknown if we lost them.

By documenting the varied relationships that humans maintain with plants, ethnobotany is at the convergence of much valuable yet threatened knowledge and practice. Therefore, ethnobotany helps to better interpret the archaeobotanical record by shedding light on the actions and strategies that cultures have applied to their own environment.

This article begins by reflecting on how climate change related phenomena are affecting or could affect archaeobotanical remains, and then offers an insight into the potential of the main proxies of archaeobotany to shed light on ecological biodiversity and human resource use, supported by different examples from the Iberian Peninsula. The choice of the Iberian Peninsula as a study area was not taken at random. In the first place, it is an area with very rich archaeological heritage and, secondly, it is one of the regions, along with southern and south-eastern Europe, most affected by extreme weather events (Carvalho, Cardoso Pereira, and Rocha 2021; Pereira, Carvalho, and Rocha 2021), together with other Mediterranean regions. For those reasons, it can be considered a representative example of the potential risks that many areas will face in the next decades.

Finally, we call for action to mitigate the effects and fight against climate change. Specifically, we wish to draw archaeologists' attention to the importance of sampling and recovery to protect archaeobotanical heritage, and we appeal to research institutions to develop contingency plans and to the different policy makers to apply measures to slow down the global warming process.

Table 1. Overview of potential information, current threats and mitigation for each type of archaeobotanical remain.

Type of remains	Potential information	Current threats	Mitigation strategy
Pollen in dry archaeological sites	Vegetation and climate reconstruction, environmental changes, anthropogenic influence, plant resources.	Partial loss of pollen and spores due to the alternation of wet and dry conditions and other post-depositional processes	Avoid erosion dynamics and sampling in parallel to excavation
Pollen in wet contexts	Vegetation and climate reconstruction, environmental changes, anthropogenic influence, plant resources.	Desiccation with consequent loss of pollen and spores	Preservation of humidity conditions if possible and if not, sampling and preservation of samples in acceptable humidity conditions. The obtention of cores could be an efficient (and faster) strategy against an immediate risk of desiccation to obtain sediment samples from wetlands to develop palynological studies.
Phytoliths offsite in wet contexts	Plant management, cultivation, vegetation reconstruction (functional characteristics of the vegetation), palaeoclimate changes, human impact on landscapes	Flooding, soil washing, landslides	Micro sampling strategy Coring or test pit sampling
Phytoliths in burned contexts	Firing practices, pastures, slash and burn, crops	Soil disturbance	Micro sampling strategy Coring or test pit sampling
Phytoliths in archaeological sites	Food, Cooking, Plants use, cultural practices	Flooding, soil washing, soil disturbance	Urgent excavation of sites Micro sampling strategy
Wood charcoal	Vegetation (arboreal forest cover), anthropogenic impact, climatic and environmental variations. Wood uses for firewood and raw material	Sample processing unavailable due to water crises	Use water recycling systems
Waterlogged macroremains	Available resources. Food, medicine and raw material with special insight into plants (e.g. oleaginous) that preserve badly through drying/charring. Cultural practices/preferences.	Desiccation due to extreme drought events. Sample processing unavailable due to water crises	Evaluation of vulnerable sites. Urgent excavation
Dried macroremains	Available resources. Food, medicine and raw material. Cultural practices/preferences.	Deterioration due to unusual storm/flood phenomena. Sample processing unavailable due to water crises	Evaluation of vulnerable sites because of geographical or topographical location. Urgent excavation
Charred macroremains	Available resources. Food, medicine and raw material. Cultural practices/preferences.	Fragmentation due to rapid changes from dry to wet and vice versa. Washing/displacement because of violent floods. Sample processing unavailable due to water crises	Evaluation of vulnerable sites because of geographical or topographical location. Urgent excavation
Frozen macroremains	Available resources. Food, medicine and raw material. Cultural practices/preferences.	Deterioration due to thawing of permafrost. Sample processing unavailable due to water crises	Urgent excavation and study

Type of remains and how they may be affected by climate change

Climate change may affect the varied plant materials differently (Table 1). Diverse parts of the plant may survive unevenly as plant tissues display differential longevity before becoming integrated in the environment that would preserve them (Alonso 2000; Antolín 2016; Buxó, Peña Chocarro, and Piqué 2003). Extreme and stable conditions, with very cold temperatures or very dry environments, can preserve organic material by freezing or drying it, preventing decomposition processes of the plant tissues (Badal et al. 2003; Zapata-Peña 2002).

In the case of the taphonomy of **phytoliths**, the deposition once the plant dies, decays or burns is considered *in situ* (Strömberg et al. 2018). Although translocation or percolation processes are generally considered imperceptible (Fishkis et al. 2010), they may be produced by extreme weather events such as windstorms (Piperno 2006). Even if their silicious nature renders better preservation compared to other archaeobotanical remains, they can be altered for instance by alkaline soils, especially with a pH above 8 (Cabanes, Shahack-Gross, and Hardy 2015; Piperno 2006). While phytoliths are resistant to most taphonomic processes, increases in pH are a factor that can lead to their dissolution.

In the current context of climate change, extreme processes can cause still unknown abrupt changes in soil pH that would have a differential effect depending on the morphotype and type of phytolith decoration, extensively damaging the assemblages (Cabanes, Shahack-Gross, and Hardy 2015). pH normally increases with rising temperatures and declining rainfall (Gray, Bishop, and Smith 2015), which is precisely the case scenario in the Iberian Peninsula, and, in consequence, may become a relevant bias for archaeological interpretations. In the specific case of the pyroarchaeological record, the effect of wetting-drying processes can be even more damaging. The pH of ash is high *per se*, which is unfavourable for the preservation of phytoliths, and that can be aggravated by the reaction of ash with water during, for example, the frequent presence of standing water that follows torrential rain, damaging a large part of the preserved phytolith assemblages.

We have already seen how torrential rains may affect a given phytoliths assemblage; for instance, at Cova Gran de Santa Linya (Lleida) (Mora et al. 2011), phytoliths studies have revealed the presence of water seepage in the cave wall, which has altered the assemblages closest to the wall. This shows that the phytoliths have suffered severe dissolution and fragmentation processes, which significantly limits the archaeological interpretation of the Palaeolithic fires and the habitat structures (Burguet-Coca 2020).

Additionally, the increase in fire events caused by both anthropogenic forest management and global warming implies a significant impact on the micro-remains record. Also, after fires, alluvial erosion events could affect palaeosoil and archaeological site preservation. Together with intense rainfall, this affects the soil surface and favours the washing out of soil particles (Ioras, Bandara, and Kemp 2014), which includes phytoliths. All these extreme weather events, such as heatwaves, droughts, floods, and wildfires, are expected to increase in frequency, severity, and intensity (Pereira, Carvalho, and Rocha 2021).

In turn, **pollen** assemblages embedded in sediments represent previous deposits from which the vegetation of the past can be reconstructed. This idea assumes that modern vegetation, its pollen rain, and its adaptive patterns are analogue to those in the past (Dincauze 2000). Several biostratinomic factors could affect the palynological record, such as production, transport, and deposition, which are specific to each pollen taxa (Hunt and Fiacconi 2018). After the deposition and burial, some fossil-diagenetic agents can also alter the fossil pollen spectra, resulting in a distortion of the original pollen rain in both natural and archaeological deposits (Lebreton et al. 2010).

The agents that cause alterations to pollen during its transport and after its deposition are generally classified as mechanical, physicochemical, and biological (Bryant and Holloway 1983). In addition to the phenomena of transport, sedimentation and fossilization, other processes related to the differential characteristics of the pollen grain structure may determine the incidence of taphonomic alterations. Although the outer wall of pollen grains, the exine, is made of an extremely resistant biological material called sporopollenin, it can be compromised and deteriorate (Lebreton et al. 2010). This is the case of some grains with thinner exine (e.g. *Juniperus* sp. or *Buxus sempervirens* L.)(that could be affected by a variety of disturbance factors (Campbell and Campbell 1994)).

In any case, it seems that there is no doubt that a high degree of oxidation is an alteration mostly linked to the incidence of fire in the pollen spectra, prior to its definitive burial. Fire is an extreme case of oxidation, which destroys or damages pollen very rapidly when sufficient oxygen is available (Lebreton et al. 2010). Furthermore, Bryant (1969), among others, established that high pH tends to result in poor conservation of palynomorphs. In fact, certain chemical compounds, especially those of a basic nature such as magnesium, potassium, sodium, and carbonates may degrade the pollen wall (Havinga 1971).

Post-depositional damage may also be related to moisture fluctuations related to evaporative processes, temperature, or hygrometry variations (Twiddle and Bunting 2010), or to alkaline/oxidative environmental alternation (Tian et al. 2009), and could cause alterations of mechanical origin, leading to a loss of the structural integrity of pollen (Campbell 1991). Some of these disruptive agents can even affect pollen after sedimentation due to reworking or redeposition of sediments (Campbell 1999).

Therefore, not all sediments are susceptible to containing pollen remains, with the most favourable to be those deposited under anoxic conditions, in extreme arid conditions (absence of microorganisms) or in stable humidity and temperature conditions (i.e. cave records, Carrión et al. 2018; Ochando et al. 2020; Revelles et al. 2022). In that sense, degradation of pollen, like other organic remains, is most affected by repeated wetting and drying rather than prolonged dryness (Davis 1990). The effect of climate change on pollen preservation is influenced more by seasonal variability in specific contexts rather than by the overall trend towards increasing aridity. In that sense, climate change causing a stable warmer and more arid climate would not affect pollen remain preservation, whereas more pronounced seasonality and prolonged summer drought would affect certain deposits, like those in wetlands or ephemeral lagoons. The main consequence of this kind of climate impact would be the lack of proper depositional conditions for the preservation of pollen; in other words, it would affect future palynological studies. These changes in climate conditions would not affect substantially the fossil record, perhaps only sub-recent material, due to the fact that palynology works with long core sequences and climate change would affect the first centimetres (or few metres), depths that past climate change has already affected, as in the case of many lagoons and wetlands in the Mediterranean in the context of increasing aridity during the Late Holocene (last 4200 years) (Burjachs et al. 2016; Revelles et al. 2015). Luckily, the expected impact of climate change in the palaeopalynological record would be limited to specific cases, such as archaeological sites in wetland areas which, although abundant in temperate Europe, are scarce in the Mediterranean region.

In any case, the influence of taphonomic processes on the pollen record is not substantial enough to prevent the reconstruction of the vegetation and climate context. Therefore, many of the alterations we see in the pollen spectra do not imply that we cannot attempt palaeoenvironmental reconstruction, provided that the climatic and environmental dynamics have not been overly drastic. It does not appear that anthropogenic pressure was responsible for the loss of resolution of the pollen record, although we can clearly see its traces in the transformation of the environment (Carrión et al. 2009; Edwards et al. 2015; Revelles 2017). What we know is that, in the past, some meteorological phenomena caused by an altered climatic context led to the loss of the palynological record (Carrión et al. 2009; Hunt and Fiacconi 2018). It is therefore to be expected that the biostratinomic and fossil-diagenetic processes linked to abrupt climate events, which are becoming more frequent, could contribute increasingly to the inevitable discontinuity of the pollen record: for example, heavy rainfall causing floods and soil erosion.

In sum, micro-remains can be influenced greatly by the effects of climate change. Extreme temperatures can translocate micro-remains such as phytoliths; intense rainfall can generate wetting-drying processes that affect the pH where phytoliths are deposited and alter them chemically, as well as harming the structural integrity of pollen; wildfire can cause an extraordinary contribution of modern phytoliths or generate extreme oxidation processes that alter pollen; and changes in temperatures can cause phenotypic changes in plants and modify pollen rain. All these extreme weather events, such as heatwaves, droughts, floods, and wildfires, are expected to increase in frequency, severity and intensity, especially in the Iberian Peninsula (Pereira, Carvalho, and Rocha 2021).

Regarding plant **macro-remains**, namely seeds, fruits, underground storage organs, wood and charcoal, preservation constraints seem to affect them more drastically than they do micro-remains. In water-saturated environments where there is little oxygenation, the action of bacteria and fungi is inhibited, resulting in optimal preservation of plant matter (Jacomet 2013). The most common cases are lake areas, peat bogs, levels below the water table (e.g. wells), and permanently humid clay levels in some caves. These conditions allow the preservation of uncharred plant material in different forms: leaves, roots, stems, branches, fruits, and seeds, but are scarce in the Iberian Peninsula. The few available cases provide an unmatched source of information, but their preservation is strongly conditioned by the water table level, which is constantly lowering across the peninsula due to the decrease in seasonal rains.

Dry conditions are also a possible means of preservation for uncharred organic materials. However, in the Iberian Peninsula, and the south Mediterranean region in general, they are reduced to a few specific areas and assemblages, as explained below. Therefore, charring is in fact the most common form of preservation, which takes place when plant remains reach a very high temperature without sufficient oxygen to burn completely. The combustion temperature may depend on the atmospheric conditions, the type of fuel and its state, the area where the fire was made (outdoors, ovens, etc.). Instead of being burned to ashes, the organic components of the plant are converted into archaeological material that is highly resistant to rotting. This charring can be accidental (during food processing or uncontrolled fires) or intentional (because of litter disposal) (Zapata-Peña 2002).

Once charred, seeds and fruits are preserved in virtually any type of substrate, so that their main preservation problem is their fragility in combination with the post-depositional taphonomic processes they may suffer. They are frequently located in the same place where they were burned or spread to nearby occupation levels, providing additional information about the use of the site (Badal et al. 2003; Zapata-Peña 2002; Zapata-Peña and Figueiral 2003).

When these conditions are fulfilled and an archaeological sampling protocol is applied, it is possible to retrieve seeds, fruits and the different elements that are part of them (Zapata-Peña and Figueiral 2003). However, changes in humidity and even in water table levels, due to drought or flooding processes derived from extreme climatic conditions, may affect waterlogged, dried, and charred remains, limiting their recovery (Table 1). On another note, the most effective and usual ways of sample processing, flotation, and water screening, require large amounts of water, especially during summer when most of the fieldwork takes place. For the Iberian Peninsula, that means that, under the current drought emergency, the correct retrieval of archaeobotanical remains is already conditioned from the first steps in their recovery. In these very days (February 2024), after more than 1000 days of drought, the Catalan government has formally announced a state of emergency, extending water restrictions to Barcelona and the surrounding region. Inhabitants of

Barcelona have a daily consumption limit of 200 litres. A flotation machine requires almost twice this volume of water per day (see e.g. Hunter and Gassner 1998). A possible solution is the adoption of water recycling systems (e.g. Shelton and White 2010), which implies additional work and economical effort, but this solves the problem only partially.

An overview of potential information to be lost

Archaeology, as a discipline specialized in the study of past human behaviour, has developed a series of tools that provide a valuable point of view to understand different issues related to climate change. For instance, throughout history, humans adopted strategies to face constraints, as proved by the evidence from archaeological sequences all over the world. They include cases of both adaptation and extinction of populations as extremes in a range of possible situations. All of them are helpful to make better predictions for our present and future.

One example is the wide array of strategies that humans have employed to maintain or increase the *carrying capacity* of a particular environment. This heterogeneity in strategies is related to cultural diversity (Burke et al. 2021). It is not fortuitous that higher biodiversity scores are generally located in indigenous territories (Garnett et al. 2018). In consequence, more detailed knowledge of some of these cases, through archaeology or TEK, will allow us to establish patterns of human-landscape relationships that can be compared with the current situation, raising questions about our own relation with the environment. From our discipline, this can be appreciated specifically in the production of food: in most non-westernized societies food production/consumption is a highly symbolic activity with different rituals associated. However, in westernized societies this activity has become more pragmatic. In fact, much of the biodiversity loss is due to this utilitarian conception of the natural world as a resource: not only animals but forests, minerals and other humans are considered resources. Under this framework, archaeobotany and the study of TEK mutually enrich and complement each other, especially, in those regions where continuity in occupations and/or practices of resource management has been assessed. Previous studies have used current TEK to interpret archaeobotanical assemblages and reconstruct the history of a particular human group (e.g. Berihuete-Azorin 2010; Dilkes-Hall et al. 2019; Kasper and McBride 2012) or the other way round: they dig into the origin of current TEK using archaeological and archaeobotanical information (e.g. Biagetti et al. 2022; Lee, Kim, and Lee 2023).

In the archaeobotanical record, plant assemblages of all types are archives that furnish an invaluable source of information about the relationship between plants and humans. **Phytoliths**, together with other micro-remains (pollen, starch, diatoms, spherulites, etc.) are often the most common remains of productive activities carried out by prehistoric communities at sites, such as the storage and processing of plants for human consumption or the use of plant resources (Kadowaki et al. 2015). The taxonomic ascription of phytoliths requires the application of geometric morphometrics (Portillo et al. 2019) and has been developed mainly for domestic plants, such as wheat, barley or barley grass (Ball, Ehlers, and Standing 2009). However, phytolith studies can provide a broader insight into plant exploitation.

For instance, phytolith analysis from Cova Gran de Santa Linya (Les Avellanes, Lleida) shows the presence of wood morphotypes in the combustion structures and an absence of tree leaf morphologies. This suggests that the wood was harvested when it was dead and had lost its leaves (Burguet-Coca 2020). In several peninsular caves and rock-shelters, the study of phytoliths has been able to characterize the main animal husbandry practices and animal diet (Alonso-Eguiluz et al. 2023; Bergadà and Oms 2021; Burguet-Coca et al. 2020), while the presence of phytoliths at high mountain sites supports a reinterpretation of the arrival of Neolithic novelties in some regions (Piqué et al. 2021; Rodríguez-Antón 2023).

Pollen, spores and palynomorphs are potentially preserved indefinitely, as demonstrated by their retrieval in Precambrian rocks, in the case of their oldest manifestations: the so-called 'acritarchs' (e.g. Moczydlowska 1991; Xiao et al. 2022). However, the conditions for their preservation must be ideal, and this is not common (see previous section).

For example, most archaeological sites in arid and temperate regions such as the Mediterranean do not usually preserve pollen material in their sediments, and, at most, only a few NPPs. This matter was the object of a synthesis for the Iberian Peninsula, detailing a large number of deposits analysed up to that time (Carrión et al. 2009). Nonetheless, those sites where pollen material has been preserved provide important information about the local landscape, its evolution during the different phases of occupation, as well as the distribution of economic or social activities related to the management or cultivation of particular plants. In this sense, palynological research carried out at the Neolithic site of La Draga (Banyoles, see Figure 1) is the best example. Firstly, the diachronic study of the pollinic material in the archaeological profiles enabled a reconstruction of the evolution of the local landscape from the first Neolithic communities, and the environmental impact of the establishment of this Neolithic settlement on the shores of the Banyoles Lake (Revelles, Burjachs, and van Geel 2016). Secondly, the study of the spatial distribution of pollen and NPPs allowed the identification of structures or areas of cereal processing (Charton 2022; Revelles 2021; Revelles et al. 2017).

Multiple archaeobotanical studies, focused on **seed** and **fruit** remains, offer an overview of plant use in the past in the Iberian Peninsula. For instance, in the Mediterranean area, a certain pattern in the use and consumption of plant resources has been established for

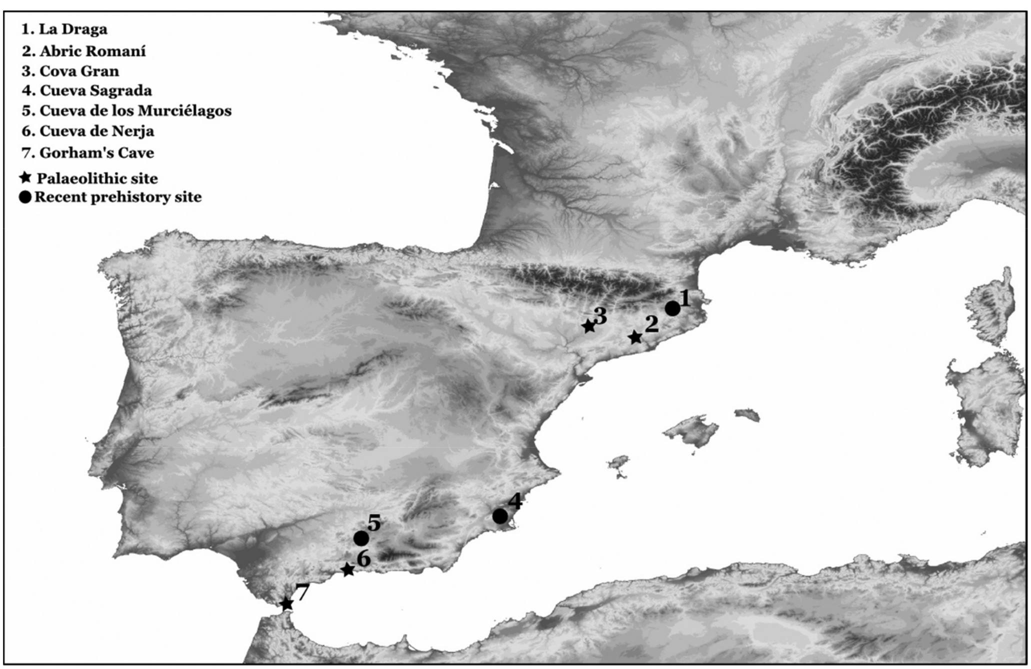

Figure 1. Location of the sites mentioned in the text.

the Palaeolithic and Mesolithic periods, including acorns (*Quercus* sp.), blackberries (*Rubus fruticosus* L.), hazelnuts (*Corylus avellana* L.) and walnuts (*Juglans regia* L.). During the Neolithic, a range of new species are identified, especially cereals, such as hulled and naked barley (*Hordeum vulgare* L.- *Hordeum vulgare* L. var. *nudum*), wheat (*Triticum turgidum* L. subsp. *dicoccum*, *Triticum monococcum* L. *Triticum aestivum/durum* L.) and pulses like lentils (*Vicia lens* Coss. & Germ) or peas (*Lathyrus oleraceus* Lam.). During the Chalcolithic and early Bronze Age the most significant change is the major exploitation of fruit trees like figs (*Ficus carica* L.) or wild grapes (*Vitis vinifera* L. sp. *sylvestris*) (Martínez-Varea 2022). Geographical and chronological variations in species may respond to different factors, such as cultural, social (number of people to be fed or able to collaborate in the gathering/cultivation), or technological (development of the knowledge and access to tools) aspects but also could be due to landscape and climatic transformations. Moreover, this information, combined with anthracology and pollen data, may show which plants are native to a specific area, informing of potential 'crops' adapted to the climatic and edaphological conditions of a specific region, and therefore more resilient and likely to survive.

Most of the remains supporting such interpretations have been preserved by charring and are therefore quite stable and resistant to degradation caused by climatic phenomena (Table 1). However, some key sites (see Figure 1), which are very special due to the kind of material preserved and the type of preservation, may suffer under extreme flooding or drought events, as well as wildfires. This is the case of Cueva de los Murciélagos (Granada) with the presence of desiccated remains of ropes and basketry (including several pairs of sandals) (Martínez-Sevilla et al. 2023); or Cueva Sagrada (Murcia) with remains of flax, esparto grass, and vine and acorn seeds (Ayala Juan 1987). At the other extreme, sites like La Draga with waterlogged anaerobic conditions, where many tools and remains made of wood and plant fibres have been recovered, may suffer from changes in the water table level (López-Bultó and Piqué 2018; López-Bultó et al. 2020).

On another note, **wood** can be preserved when carbonized, providing evidence of firewood and past vegetation based on anthracological methods. Wood was the main source of fuel in the Mediterranean area throughout different periods and, beyond taxonomic identification, other avenues of research have been developed to identify firewood qualities using signs of decay and diversity patterns (Allué and Mas 2020) or forest management (W. A. Out, Vermeeren, and Hänninen 2013; W. Out et al. 2020). Regional studies cover most of the Mediterranean and temperate regions of Europe and Western Asia, whereas charcoal studies in other areas such as the tropics are still incipient. We know that firewood was available and abundant during most periods at least in the Mediterranean and temperate areas in northern latitudes. Also, other biofuels were used such as pinecones identified at Gorham's Cave (Carrión et al. 2008) and Cueva de Nerja (Badal 1998) (see Figure 1); grasses, bone or fats may have been used to supplement the main fuel supply, or occasionally exploited for specific purposes (Madella et al. 2002; Marquer et al. 2010). Dung has also been identified as a fuel source, whose use in some regions was associated with the increase in livestock and wood scarcity (Lancelotti 2018; Shillito et al. 2022). During prehistory the emissions produced by these fuels were probably affecting only individuals' health through the inhalation of smoke (Shillito et al. 2022). In contrast, the effects on the climate were probably minor; signs of pollution have been recognized from the start of metallurgy onwards and increased during historical periods (Nocete et al. 2005; Shillito et al. 2022). Anthracological studies have helped to reconstruct wood selection processes, environmental conditions, and the use of space over time. For example, in Abric Romaní (Figure 1), hearths were structured in their morphologies, distribution and association with other remains such as bone and lithic industry (Vallverdú et al. 2010). In this case, the recurrent exploitation of montane pine wood for fuel has been shown for successive occupations at the rock-shelter between *ca* 40 and 60 kr BP (Allué, Solé, and Burguet-Coca 2017)

Even though there is much more to learn from assemblages that have not yet been studied, the corpus of information available is already quite large and at the same time the increasing use of big data and machine-learning algorithms applied to archaeology is leading towards the creation of huge repositories and relational databases. In the Supplementary Material we offer a more detailed overview of this question.

Conclusions and future actions for a brand-new world

As shown, archaeobotanical remains provide a large volume of information that is a cornerstone in the reconstruction and interpretation of our past and that may potentially enclose indications of how humans have adapted to climate challenges in different periods. These data even furnish detailed information about species that were used in the past and that may be more suited for local use owing to greater climatic resilience and better adaptation capacity to small scale and local management. In consequence, the loss of this substantial part of the palaeobotanical and micro-archaeological record can make it difficult to understand both past human activities and the reconstruction of their cultural landscapes.

The greatest threat to archaeobotanical remains preservation are human actions, such as political and economic decisions concerning urban planning and the tourist industry, which are agents seriously threatening the preservation of cultural (archaeological) and natural (wetlands) heritage, in addition to other evident threats, such as wars and other social conflicts.

However, the current climatic crisis, with its political, social and economic implications, is a new risk for archaeological heritage in general, and for the naturally delicate archaeobotanical remains. As archaeobotanists we are concerned about this situation and encourage administrations and policymakers to take direct action by regulating the protection of all archaeological materials, including archaeobotanical remains, and support with all possible means the correct excavation and sampling of archaeological sites, especially those at higher risk of affectation by extreme climatic events: waterlogged sites affected by alterations to the water table or river, lake and coastal changes; dry sites affected by rapid changes in humidity or sites located on river banks or similar, which could suffer from violent floods, as well as the destructive potential of wildfires.

On another scale, this urgency needs to be understood also by archaeologists in charge of excavations, who need to integrate archaeobotanists in their teams and archaeobotanical sampling in their fieldwork/scientific objectives, not as a complement, but as a basic and necessary source of information. The scientific community is already concerned about the effects of the climate crisis and how it will potentially impact life on Earth, and the archaeology community should explore, prepare, and draw a line of action about how the discipline is going to be affected.

Lastly, we call on the wider community, students and the general public to engage with the wide range of possible actions destined to draw attention and to change the course of events. Preserving our planet is as important as preserving TEK and archaeological heritage, so that it continues to be possible to live on it and there is room for enjoying art and heritage. There are already some collectives working in mutual aid projects to support archaeologists (e.g. https://blacktrowelcollective.wordpress.com/) as well as acting to draw the attention of society and states towards the pressing necessity of a deep systemic change (e.g. https://scientistrebellion.com/.), because this world is worth fighting for!

Acknowledgments

We are very grateful to the two anonymous reviewers whose suggestions improved our manuscript. We would also like to thank all the researchers quoted in this article, who have provided crucial information on past human adaptations, which are essential today if we are to find solutions to the climate crisis. We are especially thankful to all activists fighting against climate change.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

M.B.-A. is funded by the MCIN/AEI/10.13039/501100011033 and the European Union NextGenerationEU/PRTR [RYC2021-032364-I]. C.K. is a recipient of Juan de la Cierva-Formación contract FJC2021-046496-I funded by MCIN/AEI/10.13039/501100011033 and by the European Union "Next Generation EU"/PRTR. Research by A.B.-C., I.E. and E.A. is funded by the Spanish government research projects [MICINN-FEDER PID2021-122355NB-C32, MINECO PID2019-103987GB-C31] and the Generalitat de Catalunya research project 2021 PFR-URV-1237. This research has been supported by the Spanish Ministry of Science and Innovation through the María de Maeztu excellence accreditation [CEX2019-000945-M]. Research by E.A. is supported by MSCA-Staff Exchange 2022 ARCHBOTANKA (GA 101130984) and Fundación PALARQ. A.B.-C. has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No [HORIZON-MSCA–2021–PF-01 ID: 101063904]. F.B. is a Catalan Institution for Research and Advanced Studies Research Professor. B.G.-P. has received funding from Joan Oró FI-AGAUR [Agència de Gestió d'Ajuts Universitaris i de Recerca] for her PhD project, under the fellowship code 2023 FI-1 00512. J.R. developed this research with a Juan de la Cierva Incorporación (IJC2020) (MCINN, Spain) contract. A.R. is a MSCA-COFUND 2020 R2STAIR fellow at IPHES-CERCA and participant in projects funded by the MINCyT and SeCyT-UNC (Argentina) at IDACOR-CONICET. C.S.'s postdoctoral contract for the project "SILVA – Sicilian small IsLands Vegetation under the effect of the human Arrival" is part of the European Union's Horizon 2020 research and innovation programme "Marie Skodowska-Curie", from the State Research Agency of the Spanish Ministry of Science and Innovation through the Program Maria de Maeztu Unit of Excellence and CERCA, Centres de Recerca de Catalunya, grant agreement [101034349].

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References

Allué, E., and B. Mas. 2020. "The Meaning of *Pinus Sylvestris*-Type Charcoal Taphonomic Markers in Palaeolithic Sites in NE Iberia." *Journal of Archaeological Science: Reports* 30:102231. https://doi.org/10.1016/j.jasrep.2020.102231.

Allué, E., A. Solé, and A. Burguet-Coca. 2017. "Fuel Exploitation Among Neanderthals Based on the Anthracological Record from Abric Romaní (Capellades, NE Spain)." *Quaternary International* 431:6–15. https://doi.org/10.1016/j.quaint.2015.12.046.

Alonso, N. 2000. "Cultivos y producción agrícola en época ibérica." *Sagvntvm Papeles del Laboratorio de Arqueología de Valencia* 3:25–46. https://ojs.uv.es/index.php/saguntumextra/article/viewFile/2867/2446 .

Alonso-Eguiluz, M., R. M. Albert, J. M. Vergès, and J. Fernández-Eraso. 2023. "New Insights into Shepherds' Activities: Multi-Proxy Approach Applied to Fumier Deposits from the North of Iberian Peninsula." *Quaternary International*, July, S1040618223002197. 683-684:145–161. https://doi.org/10.1016/j.quaint.2023.06.012.

Antolín, F. 2016. *Local, Intensive and Diverse? Early Farmers and Plant Economy in the North-East of the Iberian Peninsula (5500-2300 Cal BC)*. Groningen: Barkhuis. (Advances in Archaeobotany, vol. 2). https://doi.org/10.2307/j.ctt20p56hs.

Ayala Juan, M. M. 1987. "Enterramientos calcolíticos de la Sierra de la Tercia. Lorca. Murcia. Estudio preliminar." *Anales de Prehistoria y Arqueología* 3:9–24. https://revistas.um.es/apa/article/view/67821.

Badal, E. 1998. "El Interés Económico Del Pino Piñonero Para Los Habitantes de la Cueva de Nerja." In *Las culturas del Pleistoceno superior en Andalucía*, edited by José Luis Sanchidrán Torti and María Dolores Simón Vallejo, 287–300. Nerja, Málaga: Patronato de las Cuevas de Nerja. https://www.researchgate.net/publication/285319860_El_interes_economico_del_pino_pinonero_para_los_habitantes_de_la_Cueva_de_Nerja.

Badal, E., Y. Carrión, D. Riveraand, and P. Uzquiano. 2003. "La Arqueobotánica En Cuevas Y Abrigos: Objetivos Y Métodos De Muestreo." In *La recogida de muestras en arqueobotánica: objetivos y propuestas metodológicas*, edited by Ramon Buxó and Raquel Piqué, 19–29. Barcelona, Catalonia: Museu d'Arqueologia de Barcelona. http://bioarqueologia.cat/upload/files/recogidamuestrasarqueobotanica.pdf/.

Ball, T. B., R. Ehlers, and M. D. Standing. 2009. "Review of Typologic and Morphometric Analysis of Phytoliths Produced by Wheat and Barley." *Breeding Science* 59 (5): 505–512. https://doi.org/10.1270/jsbbs.59.505.

Bergadà, M. M., and F. X. Oms. 2021. "Pastoral Practices, Bedding and Fodder During the Early Neolithic Through Micromorphology at Cova Colomera (Southeastern Pre-Pyrenees, Iberia)." *Open Archaeology* 7 (1): 1258–1273. https://doi.org/10.1515/opar-2020-0183.

Berihuete-Azorin, M. 2010. "El papel de los recursos vegetales no leñosos en las economías cazadoras-recolectoras propuesta para el estudio de su gestión: el caso de Tierra del Fuego (Argentina)". [PhD diss.], Universitat Autònoma de Barcelona. https://tesisenred.net/handle/10803/32064?locale-attribute=en .

Berkes, F., C. Folke, and M. Gadgil. 1994. "Traditional Ecological Knowledge, Biodiversity, Resilience and Sustainability." In *Biodiversity Conservation: Problems and Policies. Papers from the Biodiversity Programme Beijer International Institute of Ecological Economics Royal Swedish Academy of Sciences*, edited by C. A. Perrings, K.-G. Mäler, C. Folke, C. S. Holling, and B.-O. Jansson, 269–287. Dordrecht: Springer Netherlands.

Biagetti, S., A. Ruiz-Giralt, M. Madella, M. Khalid Magzoub, Y. Meresa, M. H. Gebreselassie, G. M. Veesar, T. A. Abro, A. Chandio, and C. Lancelotti. 2022. "No Rain, No Grain? Ethnoarchaeology of Sorghum and Millet Cultivation in Dryland Environments of Sudan, Pakistan, and Ethiopia." *Ethnoarchaeology* 13 (1–2): 80–104. https://doi.org/10.1080/19442890.2022.2059994.

Bryant, V. M. 1969. "Late Full Glacial and Postglacial Pollen Analysis of Texas Sediments." [PhD diss.], Austin: University of Texas Library.

Bryant, V. M., and R. G. Holloway. 1983. "The Role of Palynology in Archaeology." *Advances in Archaeological Method and Theory* 6:191–224. https://www.jstor.org/stable/20210068.

Burguet-Coca, A. 2020. "El Fuego en la Prehistoria. Una aproximación arqueo-experimental al registro piroarqueológico a través de la microarqueología". [PhD diss.], Universitat Rovira i Virgili, Catalonia. http://hdl.handle.net/10803/671874 .

Burguet-Coca, A., A. Polo-Díaz, J. Martínez-Moreno, A. Benito-Calvo, E. Allué, R. Mora, and D. Cabanes. 2020. "Pen Management and Livestock Activities Based on Phytoliths, Dung Spherulites, and Minerals from Cova Gran de Santa Linya (Southeastern Pre-Pyrenees)." *Archaeological and Anthropological Sciences* 12 (7). https://doi.org/10.1007/s12520-020-01101-6.

Burjachs, F., S. Jones, S. Giralt, and J. F. L. de Pablo. 2016. “Lateglacial to Early Holocene Recursive Aridity Events in the SE Mediterranean Iberian Peninsula: The Salines Playa Lake Case Study.” *Quaternary International* 403:187–200. https://doi.org/10.1016/j.quaint.2015.10.117.

Burke, A., M. C. Peros, C. D. Wren, F. S. Pausata, J. Riel-Salvatore, O. Moine, A. de Vernal, M. Kageyama, and S. Boisard. 2021. “The Archaeology of Climate Change: The Case for Cultural Diversity.” *Proceedings of the National Academy of Sciences* 118 (30): e2108537118. https://doi.org/10.1073/pnas.2108537118.

Buxó, R., L. Peña Chocarro, and R. Piqué. 2003. “La Recuperación De Restos Arqueobotánicos En Medios Húmedos.” In . *La Recogida De Muestras En Arqueobotánica: Objetivos Y Propuestas Metodológicas*, edited by Ramon Buxó and Raquel Piqué, 49–54. Barcelona, Catalonia: Museu d’Arqueologia de Barcelona. http://bioarqueologia.cat/upload/files/recogidamuestrasarqueobotanica./pdf .

Cabanes, D., R. Shahack-Gross, and K. Hardy. 2015. “Understanding Fossil Phytolith Preservation: The Role of Partial Dissolution in Paleoecology and Archaeology.” *PLOS ONE* 10 (5): e0125532. https://doi.org/10.1371/journal.pone.0125532.

Campbell, I. D. 1991. “Experimental Mechanical Destruction of Pollen Grains.” *(Rosaceae) Palynology* 15 (1): 29–33. https://doi.org/10.1080/01916122.1991.9989387.

Campbell, I. D. 1999. “Quaternary Pollen Taphonomy: Examples of Differential Redeposition and Differential Preservation.” *Palaeogeography, Palaeoclimatology, Palaeoecology* 149 (1–4): 245–256. https://doi.org/10.1016/S0031-0182(98)00204-1.

Campbell, I. D., and S. Campbell. 1994. “Pollen Preservation: Experimental Wet–Dry Cycles in Saline and Desalinated Sediments.” *(Rosaceae) Palynology* 18 (1): 5–10. https://doi.org/10.1080/01916122.1994.9989434.

Carrión, J. S., S. Fernández, P. González-Sampériz, S. A. G. Leroy, G. N. Bailey, J. A, F. Burjachs López-Sáez, et al. 2009. “Quaternary Pollen Analysis in the Iberian Peninsula: The Value of Negative Results.” *Internet Archaeology* 25 (25): 1–48. https://doi.org/10.11141/ia.25.5.

Carrión, J. S., C. Finlayson, S. Fernández, G. Finlayson, E. Allué, J. López-Sáez, P. López-García, G. Gil-Romera, G. Bailey, and P. González-Sampériz. 2008. “A Coastal Reservoir of Biodiversity for Upper Pleistocene Human Populations: Palaeoecological Investigations in Gorham’s Cave (Gibraltar) in the Context of the Iberian Peninsula.” *Quaternary Science Reviews* 27 (23–24): 2118–2135. https://doi.org/10.1016/j.quascirev.2008.08.016.

Carrión, J. S., J. Ochando, S. Fernández, R. Blasco, J. Rosell, M. Munuera, and C. Finlayson. 2018. “Last Neanderthals in the Warmest Refugium of Europe: Palynological Data from Vanguard Cave.” *Review of Palaeobotany and Palynology* 259:63–80. https://doi.org/10.1016/j.revpalbo.2018.09.007.

Carvalho, D., S. Cardoso Pereira, and A. Rocha. 2021. “Future Surface Temperature Changes for the Iberian Peninsula According to EURO-CORDEX Climate Projections.” *Climate Dynamics* 56 (1–2): 123–138. https://doi.org/10.1007/s00382-020-05472-3.

Charton, L. 2022. “Archaeopalynology in an Early Neolithic Lakeshore Settlement. Exploring the Potential of Intra-Site Pollen and Non-Pollen Palynomorphs Indicators for Paleoecological Reconstruction and Social Use of Space at La Draga (Banyoles, Spain), Sector A.” [Master’s thesis], Universitat Rovira i Virgili.

d’Alpoim Guedes, J. A., S. A. Crabtree, R. K. Bocinsky, and T. A. Kohler. 2016. “Twenty-First Century Approaches to Ancient Problems: Climate and Society.” *Proceedings of the National Academy of Sciences* 113 (51): 14483–14491. https://doi.org/10.1073/pnas.1616188113.

Davis, O. K. 1990. “Caves as Sources of Biotic Remains in Arid Western North America.” *Palaeogeography, Palaeoclimatology, Palaeoecology* 76 (3–4): 331–348. https://doi.org/10.1016/0031-0182(90)90119-R.

Dilkes-Hall, I. E., T. R. Maloney, J. Davis, H. Malo, E. Cherel, M. Street, W. Cherrabun, and B. Cherel. 2019. “Understanding Archaeobotany Through Ethnobotany: An Example from Gooniyandi Country, Northwest, Western Australia.” *Journal of the Anthropological Society of South Australia* 43:4–32. https://anthropologicalsocietysa.com/s/JASSA-43-Dilkes-Hall-et-al.pdf .

Dincauze, D. F. 2000. *Environmental Archaeology: Principles and Practice*. Cambridge: University of Cambridge Press.

Edwards, K. J., R. M. Fyfe, C. O. Hunt, and J. E. Schofield. 2015. “Moving Forwards? Palynology and the Human Dimension.” *Journal of Archaeological Science* 56:117–132. https://doi.org/10.1016/j.jas.2015.02.010.

Emperaire, L. 2000. “La biodiversité Agricole en Amazonie Brésilienne: Ressource et Patrimoine.” *Journal d’Agriculture Traditionnelle et de Botanique Appliquée* 42 (1): 113–126. https://doi.org/10.3406/jatba.2000.3732.

Fenger-Nielsen, R., B. Elberling, A. Kroon, A. Westergaard-Nielsen, H. Matthiesen, H. Harmsen, C. K. Madsen, M. Stendel, and J. Hollesen. 2020. "Arctic Archaeological Sites Threatened by Climate Change: A Regional Multi-Threat Assessment of Sites in South-West Greenland." *Archaeometry* 62 (6): 1280–1297. https://doi.org/10.1111/arcm.12593.

Fishkis, O., J. Ingwersen, M. Lamers, D. Denysenko, and T. Streck. 2010. "Phytolith Transport in Soil: A Laboratory Study on Intact Soil Cores." *European Journal of Soil Science* 61 (4): 445–455. https://doi.org/10.1111/j.1365-2389.2010.01257.x.

Garnett, S. T., N. D. Burgess, J. E. Fa, Á. Fernández-Llamazares, Z. Molnár, C. J. Robinson, J. E. Watson, et al. 2018. "A Spatial Overview of the Global Importance of Indigenous Lands for Conservation." *Nature Sustainability* 1 (7): 369–374. https://doi.org/10.1038/s41893-018-0100-6.

Gray, J. M., T. F. A. Bishop, and P. L. Smith. 2015. "Digital Mapping of Pre-European Soil Carbon Stocks and Decline Since Clearing Over New South Wales, Australia." *Soil Research* 54 (1): 49–63. https://doi.org/10.1071/SR14307.

Havinga, A. J. 1971. "An Experimental Investigation into the Decay of Pollen and Spores in Various Soil Types." In *Sporopollenin*, edited by J. Brooks, P. Grant, M. Muir, P. van Gijzel, and G. Shaw, 446–479. New York: Academic Press. https://doi.org/10.1016/B978-0-12-135750-4.50022-5.

Howard, A. J., K. Challis, J. Holden, M. Kincey, and D. G. Passmore. 2008. "The Impact of Climate Change on Archaeological Resources in Britain: A Catchment Scale Assessment." *Climatic Change* 91 (3–4): 405–422. https://doi.org/10.1007/s10584-008-9426-9.

Hudson, M., M. Aoyama, C. Hoover, and J. Uchiyama. 2012. "Prospects and Challenges for an Archaeology of Global Climate Change." *WIREs Climate Change* 3 (4): 313–328. https://doi.org/10.1002/wcc.174.

Hunt, C. O., and M. Fiacconi. 2018. "Pollen Taphonomy of Cave Sediments: What Does the Pollen Record in Caves Tell Us About External Environments and How Do We Assess Its Reliability?" *Quaternary International* 485:68–75. https://doi.org/10.1016/j.quaint.2017.05.016.

Hunter, A. A., and B. R. Gassner. 1998. "Evaluation of the Flote-Tech Machine-Assisted Flotation System." *American Antiquity* 63 (1): 143–156. https://doi.org/10.2307/2694781.

Ioras, F., I. Bandara, and C. Kemp. 2014. "Introduction to Climate Change and Land Degradation." In *Climate Change and Restoration of Degraded Land*, edited by M. P. Arraiza Bermúdez-Cañete, J.C. Santamarta Cerezal, F. Ioras, J.L. García Rodríguez, I. Vasile Abrudan, H. Korjus, and G. Borbála, 15–52. Madrid: Colegio de Ingenieros de Montes. https://oa.upm.es/32229/1/LIBRO_RECLAND_V01.pdf.

Jacomet, S. 2013. "Archaeobotany: Analyses of Plant Remains from Waterlogged Archaeological Sites." In *The Oxford Handbook of Wetland Archaeology*, edited by Francesco Menotti and Aidan O'Sullivan, 497–514. Oxford: Oxord University Press. https://doi.org/10.1093/oxfordhb/9780199573493.013.0030.

Kadowaki, S., L. Maher, M. Portillo, R. M. Albert, Akashi Ch, F. Guliyev, and Y. Nishiaki. 2015. "Geoarchaeological and Palaeobotanical Evidence for Prehistoric Cereal Storage in the Southern Caucasus: The Neolithic Settlement of Göytepe (Mid-8th Millennium BP)." *Journal of Archaeological Science* 53:408–425. https://doi.org/10.1016/j.jas.2014.10.021.

Kasper, K., and K. A. McBride. 2012. *The Spatial Significance of Plants*. Memphis: Society for American Archaeology.

Lancelotti, C. 2018. "Not All That Burns is Wood. A Social Perspective on Fuel Exploitation and Use During the Indus Urban Period (2600-1900 BC)." *PLOS ONE* 13 (3): e0192364. https://doi.org/10.1371/journal.pone.0192364.

Lebreton, V., L. Messager, L. Marquer, and J. Renault-Miskovsky. 2010. "A Neotaphonomic Experiment in Pollen Oxidation and Its Implications for Archaeopalynology." *Review of Palaeobotany and Palynology* 162 (1): 29–38. https://doi.org/10.1016/j.revpalbo.2010.05.002.

Lee, H., Y. Kim, and G. A. Lee. 2023. "Niche Construction of Ban-Nong Ban-Eoh in Southwestern Korea: Archaeobotanical Data from the Early Iron to Three Kingdoms Periods." *Journal of Field Archaeology* 13 (6): 1–19. https://doi.org/10.1080/00934690.2023.2219933.

López-Bultó, O., and R. Piqué. 2018. "Wood Procurement at the Early Neolithic Site of La Draga (Banyoles, Barcelona)." *Journal of Wetland Archaeology* 18 (1): 56–76. https://doi.org/10.1080/14732971.2018.1466415.

López-Bultó, O., R. Piqué, F. Antolín, J. A. Barceló, A. Palomo, and I. Clemente. 2020. "Digging Sticks and Agriculture Development at the Ancient Neolithic Site of la Draga (Banyoles, Spain)." *Journal of Archaeological Science: Reports* 30:102193. https://doi.org/10.1016/j.jasrep.2020.102193.

Madella, M., M. K. Jones, P. Goldberg, Y. Goren, and E. Hovers. 2002. "The Exploitation of Plant Resources by Neanderthals in Amud Cave (Israel): The Evidence from Phytolith Studies." *Journal of Archaeological Science* 29 (7): 703–719. https://doi.org/10.1006/jasc.2001.0743.

Marquer, L., T. Otto, R. Nespoulet, and L. Chiotti. 2010. "A New Approach to Study the Fuel Used in Hearths by Hunter-Gatherers at the Upper Palaeolithic Site of Abri Pataud (Dordogne, France)." *Journal of Archaeological Science* 37 (11): 2735–2746. https://doi.org/10.1016/j.jas.2010.06.009.

Martínez-Sevilla, F., M. Herrero-Otal, M. Martín-Seijo, J. Santana, J. A. Lozano Rodríguez, R. Maicas Ramos, M. Cubas, et al. 2023. "The Earliest Basketry in Southern Europe: Hunter-Gatherer and Farmer Plant-Based Technology in Cueva de Los Murciélagos (Albuñol)." *Science Advances* 9 (39): eadi3055. https://doi.org/10.1126/sciadv.adi3055.

Martínez-Varea, C. M. 2022. "Los recursos vegetales en la economía paleolítica y mesolítica: un estado de la cuestión en la península ibérica." *Trabajos de Prehistoria* 79 (1): 30–46. https://doi.org/10.3989/tp.2022.12285.

Moczydlowska, M. 1991. "Acritarch Biostratigraphy of the Lower Cambrian and the Precambrian-Cambrian Boundary in Southeastern Poland. Lethaia." *An International Journal of Palaeontology and Stratigraphy* 29:127. https://doi.org/10.18261/8200374742-1991-01.

Mora, R., A. Benito-Calvo, J. Martínez-Moreno, P. González Marcen, and I. de la Torre. 2011. "Chrono-Stratigraphy of the Upper Pleistocene and Holocene Archaeological Sequence in Cova Gran (South-Eastern Pre-Pyrenees, Iberian Peninsula)." *Journal of Quaternary Science* 26 (6): 635–644. https://doi.org/10.1002/jqs.1486.

Nocete, F., E. Álex, J. M. Nieto, R. Sáez, and M. R. Bayona. 2005. "An Archaeological Approach to Regional Environmental Pollution in the South-Western Iberian Peninsula Related to Third Millennium BC Mining and Metallurgy." *Journal of Archaeological Science* 32 (10): 1566–1576. https://doi.org/10.1016/j.jas.2005.04.012.

Ochando, J., J. S. Carrión, R. Blasco, F. Rivals, A. Rufà, M. Demuro, and J. Rosell. 2020. "Neanderthals in a Highly Diverse, Mediterranean-Eurosiberian Forest Ecotone: The Pleistocene Pollen Record of Teixoneres Cave, Northeastern Spain." *Quaternary Science Reviews* 241:106429. https://doi.org/10.1016/j.quascirev.2020.106429.

Out, W., C. Baittinger, K. Čufar, O. López-Bultó, K. Hänninen, and C. Vermeeren. 2020. "Identification of Woodland Management by Analysis of Roundwood Age and Diameter: Neolithic Case Studies." *Forest Ecology & Management* 467:118–136. https://doi.org/10.1016/j.foreco.2020.118136.

Out, W., C. Vermeeren, and K. Hänninen. 2013. "Branch Age and Diameter: Useful Criteria for Recognising Woodland Management in the Present and Past?" *Journal of Archaeological Science* 40 (11): 4083–4097. https://doi.org/10.1016/j.jas.2013.05.004.

Pearsall, D. M. 2015. *Paleoethnobotany: A Handbook of Procedures*. London: Routledge.

Pereira, S. C., D. Carvalho, and A. Rocha. 2021. "Temperature and Precipitation Extremes Over the Iberian Peninsula Under Climate Change Scenarios: A Review." *Climate* 9 (9): 139. https://doi.org/10.3390/cli9090139.

Piperno, D. R. 2006. *Phytoliths: A Comprehensive Guide for Archaeologists and Paleoecologists*. Lanham: AltaMira Press.

Piqué, R., M. Alcolea, F. Antolín, M. Berihuete-Azorín, A. Berrocal, D. Rodríguez-Anton, M. Herrero-Otal, O. López-Bultó, L. Obea, and J. Revelles. 2021. "Mid-Holocene Palaeoenvironment, Plant Resources and Human Interaction in Northeast Iberia: An Archaeobotanical Approach." *Applied Science* 11 (11): 5056. https://doi.org/10.3390/app11115056.

Portillo, M., T. B. Ball, M. Wallace, C. Murphy, S. Pérez-Díaz, M. Ruiz-Alonso, F. J. Aceituno, and J. A. López-Sáez. 2019. "Advances in Morphometrics in Archaeobotany." *Environmental Archaeology* 25 (2): 246–256. https://doi.org/10.1080/14614103.2019.1569351.

Revelles, J. 2017. "Archaeoecology of Neolithisation. Human-Environment Interactions in the NE Iberian Peninsula During the Early Neolithic." *Journal of Archaeological Science: Reports* 15:437–445. https://doi.org/10.1016/j.jasrep.2016.02.004.

Revelles, J. 2021. "The Role of Palynology in Archaeological Research: Reconstructing Human-Environment Interactions During the Neolithic in the Western Mediterranean." *Applied Sciences* 11 (9): 4073. https://doi.org/10.3390/app11094073.

Revelles, J., E. Allué, M. Alcolea, F. Antolín, M. Berihuete-Azorin, I. Expósito, F. Burjachs, et al. 2022. "Site Formation Processes, Human Activities and Palaeoenvironmental Reconstructions from Archaeobotanical Records in Cave and Rock-Shelter Sites in NE Iberia." *Review of Palaeobotany and Palynology* 299:104612. https://doi.org/10.1016/j.revpalbo.2022.104612.

Revelles, J., F. Burjachs, N. Morera, J. A. Barceló, A. Berrocal, O. López-Bultó, and C. Maicher. 2017. “Use of Space and Site Formation Processes in a Neolithic Lakeside Settlement. Pollen and Non-Pollen Palynomorphs Spatial Analysis in La Draga (Banyoles, NE Iberia).” *Journal of Archaeological Science* 81:101–115. https://doi.org/10.1016/j.jas.2017.04.001.

Revelles, J., F. Burjachs, and B. van Geel. 2016. “Pollen and Non-Pollen Palynomorphs from the Early Neolithic Settlement of La Draga (Girona, Spain).” *Review of Palaeobotany and Palynology* 225:1–20. https://doi.org/10.1016/j.revpalbo.2015.11.001.

Revelles, J., S. Cho, E. Iriarte, F. Burjachs, B. van Geel, A. Palomo, R. Piqué, L. Peña-Chocarro, and X. Terradas. 2015. “Mid-Holocene Vegetation History and Neolithic Land-Use in the Lake Banyoles Area (Girona, Spain).” *Palaeogeography, Palaeoclimatology, Palaeoecology* 435:70–85. https://doi.org/10.1016/j.palaeo.2015.06.002.

Rodríguez-Antón, D. 2023. “L’anàlisi de fitòlits i d’altres restes vegetals: Una nova metodologia arqueoambiental aplicada a la reconstrucció dels paisatges culturals d’alta muntanya al llarg de l’Holocè.” *Treballs d’Arqueologia* 26:127–153. https://doi.org/10.5565/rev/tda.130.

Russell, J. C., and C. Kueffer. 2019. “Island Biodiversity in the Anthropocene.” *Annual Review of Environment and Resources* 44 (1): 31–60. https://doi.org/10.1146/annurev-environ-101718-033245.

Secretariat of the Convention on Biodiversity. 2011. *Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from Their Utilization to the Convention on Biological Diversity: Text and Annex*. Montreal, Canada: Secretariat of the Convention on Biodiversity. https://doi.org/10.25607/OBP-789.

Shelton, C. P., and C. E. White. 2010. “The Hand-Pump Flotation System: A New Method for Archaeobotanical Recovery.” *Journal of Field Archaeology* 35 (3): 316–326. https://doi.org/10.1179/009346910X12707321358838 .

Shillito, L. M., A. Namdeo, V. Bapat, H. Mackay, and S. D. Haddow. 2022. “Analysis of Fine Particulates from Fuel Burning in a Reconstructed Building at Çatalhöyük World Heritage Site, Turkey: Assessing Air Pollution in Prehistoric Settled Communities.” *Environmental Geochemistry and Health* 44 (3): 1033–1048. https://doi.org/10.1007/s10653-021-01000-2.

Sitzia, F., M. Peters, and C. Lisci. 2022. “Climate Change and Its Outcome on the Archaeological Areas and Their Building Materials. The Case Study of *Tharros* (Italy).” *Digital Applications in Archaeology & Cultural Heritage* 25:e00226. https://doi.org/10.1016/j.daach.2022.e00226.

Strömberg, C. A. E., R. E. Dunn, C. Crifó, and E. B. Harris. 2018. “Phytoliths in Paleoecology: Analytical Considerations, Current Use, and Future Directions.” In *Methods in Paleoecology. Reconstructing Cenozoic Terrestrial Environments and Ecological Communities*, edited by D. A. Croft, D. F. Su, and S.W. Simpson, 235–287. Springer. https://link.springer.com/book/10.1007/978-3-319-94265-0.

Tian, F., X. Cao, Q. Xu, and Y. Li. 2009. “A Laboratorial Study on Influence of Alkaline and Oxidative Environment on Preservation of *Pinus Tabulaeformis* Pollen.” *Frontiers of Earth Science in China* 3 (2): 226–230. https://doi.org/10.1007/s11707-009-0003-y.

Twiddle, C. L., and M. J. Bunting. 2010. “Experimental Investigations into the Preservation of Pollen Grains: A Pilot Study of Four Pollen Types.” *Review of Palaeobotany and Palynology* 162 (4): 621–630. https://doi.org/10.1016/j.revpalbo.2010.08.003.

Vallverdú, J., M. Vaquero, I. Cáceres, E. Allué, J. Rosell, P. Saladié, G. Chacón, et al. 2010. “Sleeping Activity Area within the Site Structure of Archaic Human Groups: Evidence from Abric Romaní Level N Combustion Activity Areas.” *Current Anthropology* 51 (1): 137–145. https://doi.org/10.1086/649499.

Xiao, S., G. Jiang, Q. Ye, Q. Ouyang, D. M. Banerjee, B. P. Singh, A. D. Muscente, C. Zhou, and N. Hughes. 2022. “Sleeping Activity Area within the Site Structure of Archaic Human Groups: Evidence from Abric Romaní Level N Combustion Activity Areas.” *Journal of Paleontology*: 1–62. https://doi.org/10.1017/jpa.2022.7.

Yin, L. 2023. “Traditional Ecological Customary Law for Conservation and Sustainability in Biodiversity.” *Sustainable Development*. https://doi.org/10.5772/intechopen.105918.

Zapata-Peña, L. 2002. *Origen de la agricultura en el País Vasco y Transformaciones en el Paisaje: Análisis de Restos Vegetales Arqueológicos*. Kobie, anejos 4. Bilbao: Bizkaiko Foru Aldundia. https://www.bizkaia.eus/fitxategiak/04/ondarea/Kobie/PDF/6/kobie_4_anejos%20volumen%20completo.pdf?hash=0f29561862ea6bae1134657c9d10c1b6.

Zapata-Peña, L., and I. Figueiral. 2003. “Carbones y Semillas En Los Yacimientos Dolménicos: Posibilidades Y Límites Del Análisis Arqueobotánico.” In *La recogida de muestras en arqueobotánica: objetivos y propuestas metodológicas*, edited by Ramon Buxó and Raquel Piqué, 55–65. Barcelona, Catalonia: Museu d’Arqueologia de Barcelona. http://bioarqueologia.cat/upload/files/recogidamuestrasarqueobotanica.pdf.